

THE WEATHER AND CIRCULATION OF APRIL 1960

A Sharp Mid-Month Drop in the Zonal Westerlies Accompanied by a Temperature Reversal in the Contiguous United States

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1. HIGHLIGHTS

After reaching its highest value since early January, the speed of the westerly winds at middle latitudes sharply dropped near mid-April 1960. This drop was associated with a return of widespread blocking to higher latitudes in the last half of April, after having been absent since the middle of March, and was accompanied by a large-scale change in the pattern of planetary waves over the United States. A marked reversal in temperature regimes over the contiguous United States was also a concomitant feature of this alteration of the general circulation.

In the West above normal temperatures, including some record-breaking maxima early in the month, gave way to below normal values in the latter part of the month as a deep planetary trough became established aloft. During this period widespread frost damage to fruit was reported in many parts of the Far West and Northwest.

In the East near to below normal temperatures were replaced by record-breaking high temperatures in the latter part of the month, consonant with the planetary ridge which became established here for the first time since the latter part of December. This reversal is reminiscent of April 1957 [1] when vigorous warming in the eastern United States in the last half of the month established many new records for warmth, despite coldness early in the month.

This April was a comparatively dry one, particularly in contrast to the extremely wet April of 1957, despite similar evolution of the temperature pattern in the two months. A number of areas this month experienced the driest conditions in 30 years or more; e.g., parts of Ohio, Mississippi, Arkansas, New Mexico, Arizona, and Wyoming. Nevertheless there were some areas of excessive precipitation, principally central Montana, the Upper Mississippi Valley, some areas along the west coast, and the Southeast. Excessive precipitation in the Southeast during the first few days of the month caused flooding in this area. Considerable flooding also occurred in the Middle West and the Northeastern States due to a combination of moderate to heavy precipitation plus rapid melting of excessive snow and ice which had accumulated

in record amounts in some places during the winter season.

Another highlight was the sudden development of a deep storm over Nevada late in the month, associated with retrogression of a planetary wave trough across western United States. This storm produced the lowest sea level pressure on record at Ely, Nev., 983 mb. on April 22, and ushered the coldest temperatures of the month into the Far West. The wind field aloft associated with this storm caused moist Pacific air to overrun a wedge of cold Polar Canadian air in Montana and produced a severe snowstorm with strong winds in central Montana from the 22d to the 24th. Great Falls received 16.2 inches during this time, the month's total.

Severe weather activity also developed near mid-month when a major trough was located near the Continental Divide. For example, Amarillo, Tex., reported that a tornado at Sunnyside, in Castro County, killed 3 and injured 66 on the 12th; while on the 16th, Tulsa, Okla., reported extensive tornado damage, St. Joseph, Mo., had wind gusts to 75 m.p.h., and Waterloo, Iowa, experienced damaging winds in connection with a severe thunderstorm. On the 26th, hail of baseball size fell on San Angelo, Tex., and on the 28th a tornado hit the southwestern part of Oklahoma City. Precipitation in connection with the storm system on the 27th and 28th totaled 2.16 inches, or two-thirds of the month's total at Oklahoma City.

In the Pacific Northwest a particularly stormy period caused property damage and power failures at Seattle, Wash., on the 13th and 14th, while Tatoosh Island experienced hurricane-force winds from this storm. It may be of interest that in the most recent analogous April (i.e., 1957) a similar coastal storm brought 70 m.p.h. gusts of wind at almost precisely the same time during the month.

All of the month's total rainfall at Los Angeles, Calif., 2.00 in. (about twice the normal amount), fell on the 26th and 27th, including a record 24-hour amount of 1.88 in.

2. MEAN CIRCULATION

MONTHLY PATTERN

The average circulation at 700 mb. for April 1960 (fig.

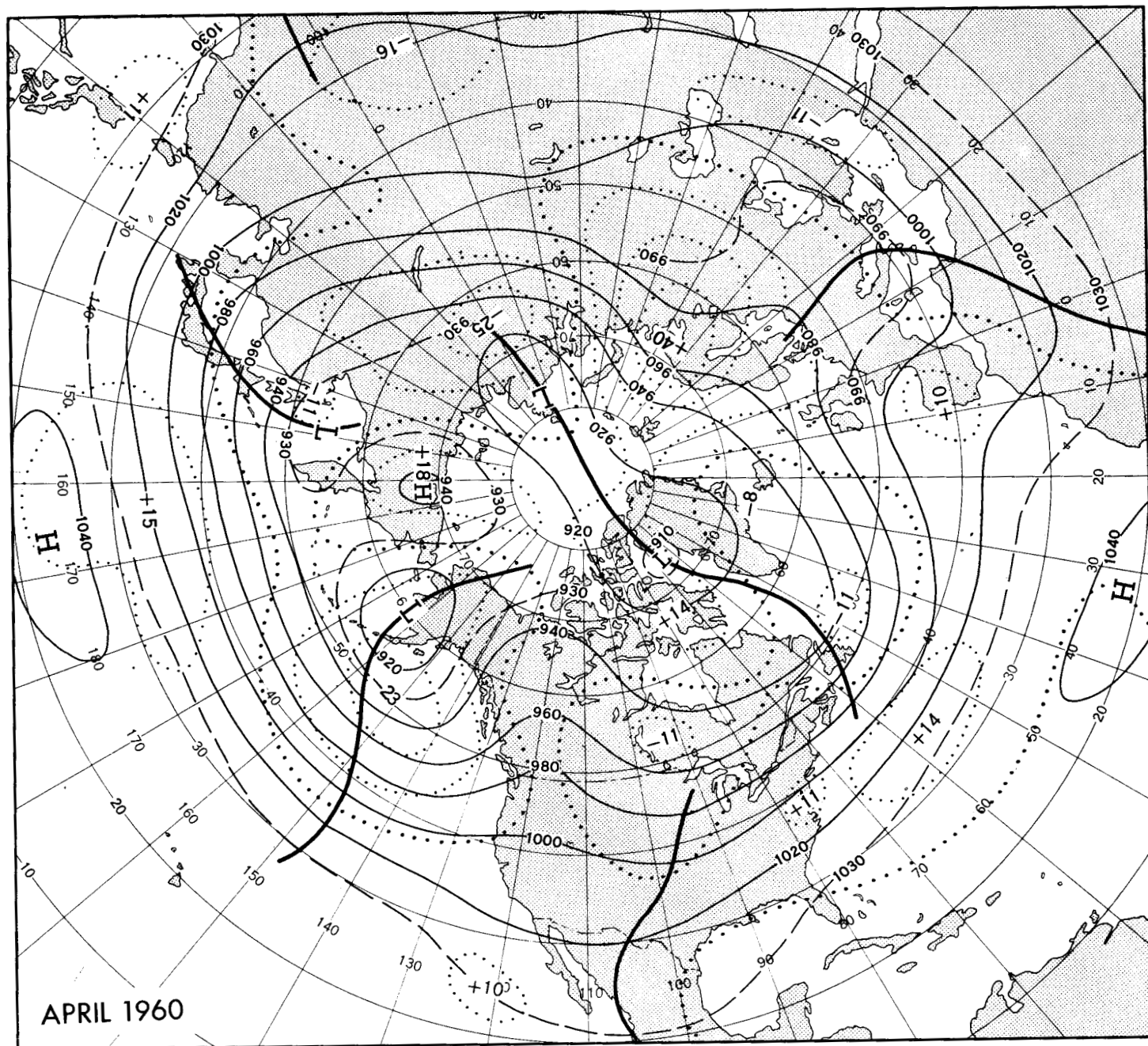


FIGURE 1.—Mean 700-mb. contours (solid) and height departures from normal (dotted), both in tens of feet, for April 1960. The trough in the central United States produced heavy precipitation in the Midwest, contributing to severe floods in the area.

1) consisted of a pattern not greatly different from normal, especially over North America, with a ridge in the West and a slightly deeper than normal trough from Iowa southwestward to Mexico. An additional center of action near southwestern Alaska and a trough extending southwestward were associated with persistent blocking in northeastern Siberia, the Alaskan Low constituting one cell of a typical "omega" block, while its twin center was displaced from its normal position to the Sea of Okhotsk. The strongest blocking in the monthly average, however, was over Scandinavia where heights averaged 400 ft. above normal.

MID-MONTH CHANGE IN CIRCULATION

For an understanding of the observed temperature and precipitation anomalies during the month (fig. 2), the two 15-day components of the April circulation are more revealing than the monthly average as a whole. The average circulation for the first 15 days of April (fig. 3A) bore a marked similarity to that of the last half of March [2]. Both periods were characterized by stronger than normal mid-latitude westerlies over the western sector of the Northern Hemisphere, averaging 11.5 m.p.s. for the first half of April. This is shown by the above normal height departures in lower latitudes and below normal

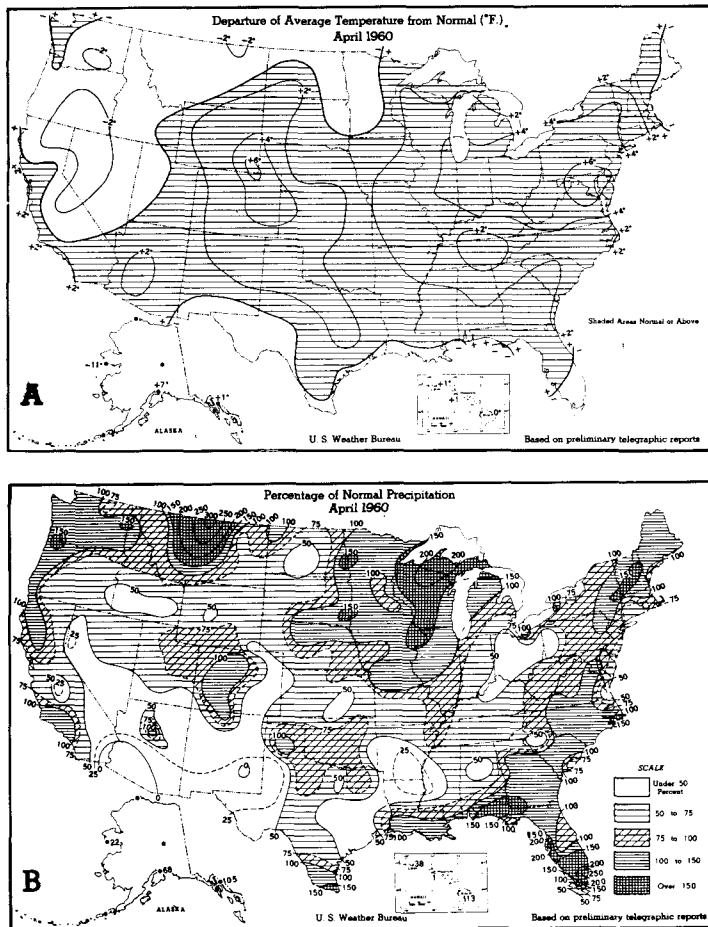


FIGURE 2.—(A) Temperature departure from normal ($^{\circ}$ F.) for April 1960. (B) Percentage of normal precipitation for April 1960. (From [3].)

departures at higher latitudes (fig. 3A). With a stronger than normal ridge in the western United States, temperatures averaged well above normal over the Rockies, while in the eastern trough temperatures averaged near normal (fig. 3B). Precipitation was predominantly light over much of the country for the 15-day average, except along the Gulf and Atlantic Coasts where stronger than normal southerly flow prevailed. Here 2.5-in. amounts were general along the middle and northern seaboard, with heavier amounts ranging to over 6.00 in. in the Southeast.

The marked change in the mean flow pattern which took place about the middle of April is perhaps best portrayed by the height changes between the first and last halves of the month (fig. 4). These changes took the form of hemispheric height rises at high latitudes with an array of fall centers at lower latitudes. This change pattern was a manifestation of a sudden and dramatic resurgence of blocking at high latitudes with a concomitant slowing down of the mid-latitude westerlies to an average of 7.5 m.p.s. for the last half of the month, as shown in the index graph (lower part of fig. 7).

This upheaval resulted in the average 700-mb. pattern

for the last 15 days of April shown in figure 3C and its associated temperature pattern, figure 3D. An interesting feature of this flow pattern was the array of "omega"-type blocks north of the westerlies almost around the hemisphere, with blocking Highs centered over Siberia, western Canada, eastern Canada, and the North Atlantic. In addition, the reversal of planetary flow patterns between the two halves of the month, with ridge replacing trough in the East and vice versa in the West, was an outstanding feature of this month's weather. As a matter of fact, the latter part of April was the first fortnight in which ridge conditions prevailed along the east coast since the latter half of December. This may be interpreted partly as a result of the persistent tendency toward blocking in North America which is known to favor depressed westerlies to the south.

THE WEEKLY EVOLUTION

Figure 5 shows a series of 5-day mean 700-mb. patterns at approximately weekly intervals, with observed temperature anomaly classes superimposed. The period April 5–9 is similar to the first 15-day average with a trough near the east coast and a ridge in the West, associated with cooler than normal conditions in the East and warmer than normal in the West.

The period April 12–16 (fig. 5B) shows conditions near mid-month, and closely resembles the monthly pattern. An over-extension of the wavelength across North America due to rapid progression of the eastern trough into the Atlantic favored the development of a new trough near the Continental Divide. The resulting backing of the mean winds over the central United States resulted in considerable warming from the Rockies eastward, while cooling occurred in the Far West, as shown by the temperature departure from normal pattern in figure 5B. The new trough also brought a return of heavy precipitation to the Midwest, further compounding the severity of the flood situation in this area. Immediately following this period, a strong blocking surge at high latitudes was manifested in a sharp drop in the speed of the temperate westerlies (fig. 7, lower chart).

Figure 5C depicts the mean flow and temperature anomaly classes for the period April 21–25. This 5-day period closely resembled the 15-day average for the latter half of the month and had the weakest westerlies at mid-latitudes since February, 5.8 m.p.s., or 2.3 m.p.s. below normal. Ridge development off the Pacific Coast together with westward migration of the Canadian block to the Great Slave Lake area provided circumstances favorable for a much deeper than normal trough in the Far West and resulted in retrogression of the trough which had been near the Continental Divide at mid-month. The consequent strengthening of the northerly flow, relative to normal, along the West Coast and of the southerly flow over the central United States resulted in the greatest contrast in temperature of the month with record heat in the East and cold in the West (fig. 5C).

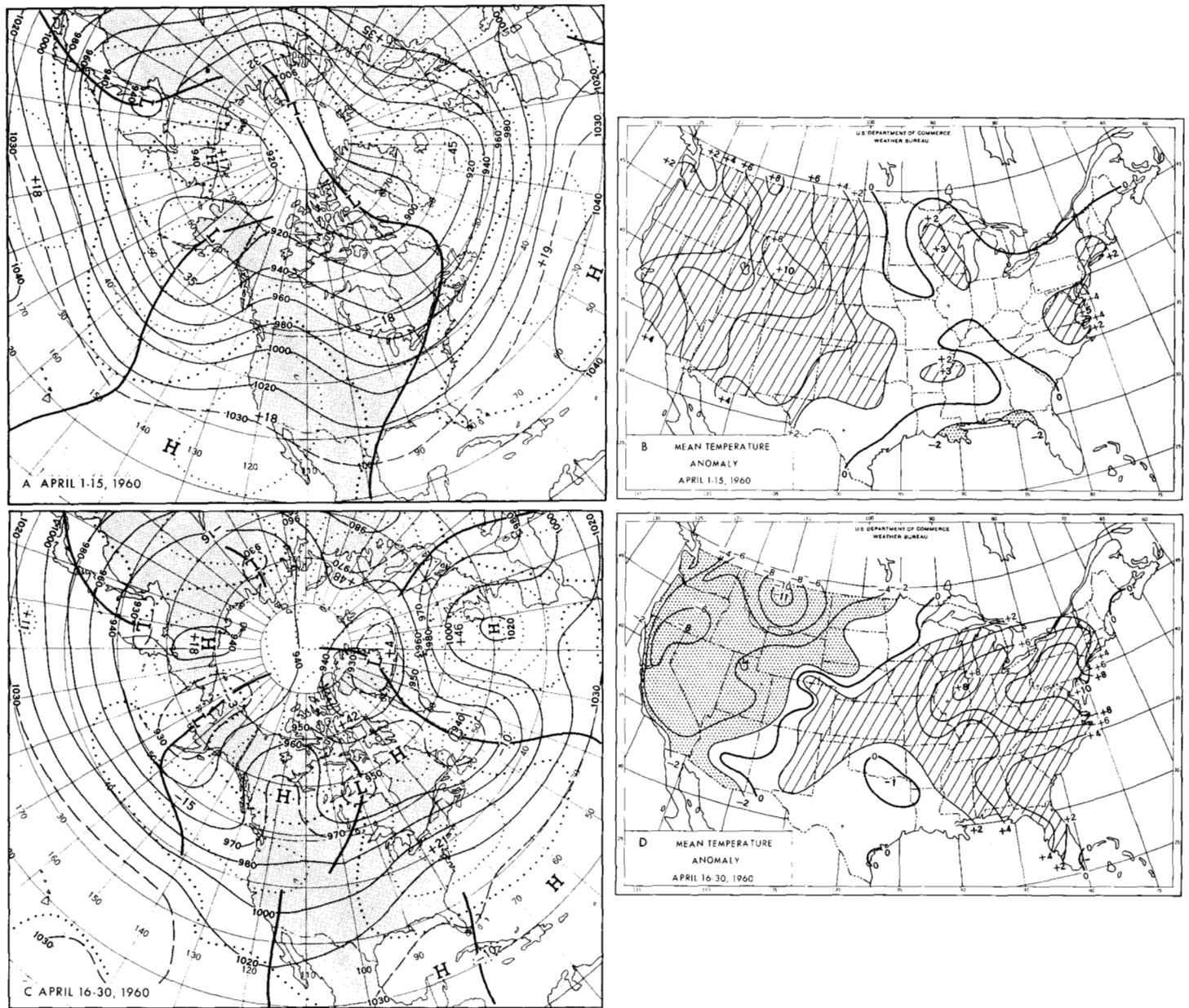


FIGURE 3.—(A) Mean 700-mb. contours (solid) and height departures from normal (dotted), both in tens of feet, for April 1-15, 1960. (B) Temperature departure from normal (° F.) for April 1-15, 1960. (C) Mean 700-mb. contours (solid) and height departures from normal (dotted), both in tens of feet, for April 16-30, 1960. (D) Temperature departure from normal (° F.) for April 16-30, 1960. The reversal of the circulation and temperature patterns over the contiguous United States was noteworthy.

3. TEMPERATURE CHANGES AND EXTREMES

It is probably not surprising that the great upheaval and associated reversal of the circulation during the month over North America were associated with extreme temperature changes and record-breaking temperatures. This was related to the enormous pressure changes which occurred to bring about such an evolution and the associated surface storminess such as that which produced the record low pressures in Nevada in the latter part of the month. The development of deep surface storms (cyclogenesis) acted to exaggerate the temperature changes which normally would be associated with planetary wave

redistribution, primarily through the development of extreme contrasts in low-level advection.

Thus new maximum temperature records for individual dates were set at scores of stations throughout the continental United States: in the East in the latter part of the month, and in the West early in the month. However, in Alaska high temperatures occurred near month's end when the Canadian block had retrograded to this vicinity.

In the eastern United States the heat wave was the more spectacular because of the record breaking cold which preceded it during March [2] and part of early April. So sharp were the contrasting regimes in the East between

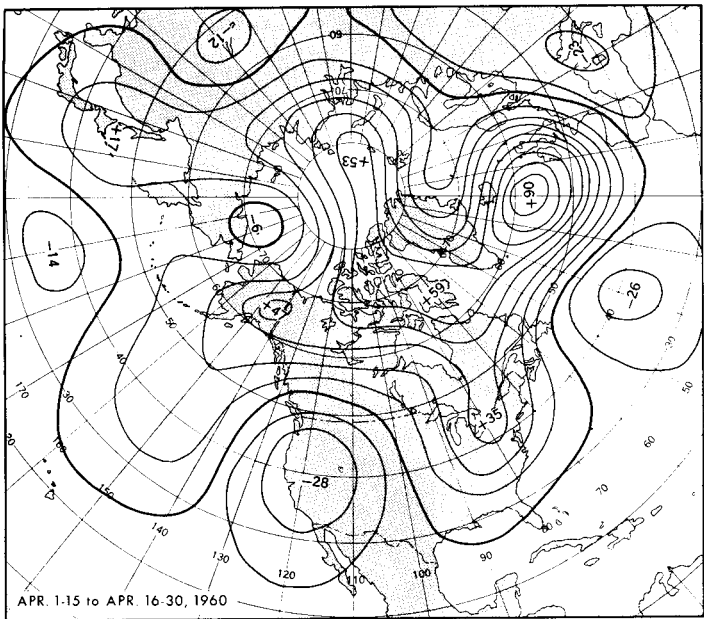


FIGURE 4.—Mean 700-mb. height changes (tens of feet) between first and last halves of April 1960 (see fig. 3). Widespread height rises at high latitudes resulted in dramatic slowing down of westerlies at middle latitudes.

TABLE 1.—Some record temperatures for indicated dates observed during April 1960

	New record maximum Date	New record minimum Date
Birmingham, Ala.	89 25	31 10
Montgomery, Ala.	74 30	
Fairbanks, Alaska	82 5	24 25
Prescott, Ariz.	101 9	
Yuma, Ariz.	89 23	
Little Rock, Ark.	86 4	
Sacramento, Calif.	92 2	
San Diego, Calif.	80 10	22 30
Denver, Colo.	81 22	
Hartford, Conn.	89 23	
Wilmington, Del.	95 23	
Washington, D.C.		23 11
Rome, Ga.		20 16
Boise, Idaho	85 22	25 10
Evansville, Ind.		21 10
Peoria, Ill.	84 23	
Burlington, Iowa	94 22	20 10
Sioux City, Iowa	91 23	
Louisville, Ky.		9 11
Caribou, Maine	95 23	
Baltimore, Md.	83 22	
Grand Rapids, Mich.		14 9
St. Cloud, Minn.	91 23	26 10
St. Louis, Mo.	80 5	23 25
Billings, Mont.	92 22	
Omaha, Nebr.	94 5	41 17
Las Vegas, Nev.	91 25	
Newark, N.J.	84 7	
Albuquerque, N. Mex.	87 23	
Binghamton, N.Y.	93 24	
Raleigh, N.C.	89 23	
Cincinnati, Ohio	92 25	
Philadelphia, Pa.		21 11
Pittsburgh, Pa.	93 25	29 11
Columbia, S.C.	85 22	33 11
Greenville, S.C.	93 22	
Sioux Falls, S. Dak.	85 22	28 10
Nashville, Tenn.		44 4
Corpus Christi, Tex.	82 9	24 17
Salt Lake City, Utah	76 17	
Burlington, Vt.	96 26	
Richmond, Va.		26 22
Spokane, Wash.	78 4	
Yakima, Wash.	89 23	
Parkersburg, W. Va.	84 22	
Milwaukee, Wis.	76 5	20 10
Sheridan, Wyo.		

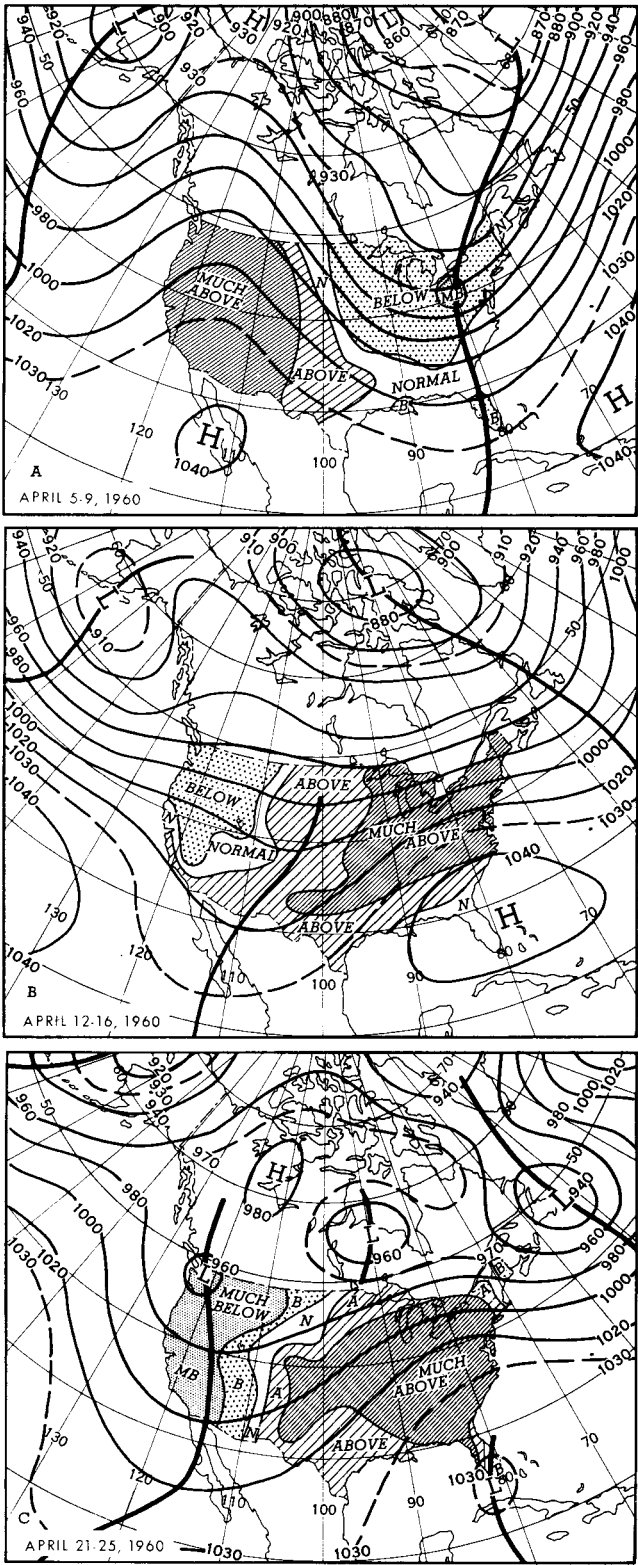


FIGURE 5.—5-day mean 700-mb. contours (solid), tens of feet, and observed temperature anomaly classes for (A) April 5–9, (B) April 12–16, and (C) April 21–25, 1960. The most noteworthy aspect of this evolution was the complete reversal in phase of the planetary wave over the contiguous United States.

the two halves of April, as well as between April and the preceding March, that winter seemed to give way abruptly to midsummer during a brief span of time near the middle of the month. Figures 3B and 3D reveal this reversal of temperature anomalies between the two parts of the month. It may also be inferred that 15-day average temperatures cooled 10° to 20° over much of the intermountain area of the West with the greatest cooling in Montana, while marked warming occurred from Illinois eastward to the Middle Atlantic coast.

In addition to numerous record maximum temperatures for individual dates, new record maxima were established for the entire month and for so early in the season. Furthermore, a number of cities near the Atlantic coast reported the highest mean temperature ever recorded for the month of April; e.g., Washington, D.C., Baltimore, Md., and Richmond and Norfolk, Va. Norfolk reported five consecutive days of record maxima, climaxed by 97° F. on the 26th. The warmest period in the East was about the 22d to the 26th (fig. 5C) when daily average temperatures rose to 26° above normal in some places. In the same period daily mean temperatures in parts of the West plunged to 20° below normal with widespread damage to fruit crops in the Pacific Northwest. Many new minimum temperature records for individual dates as well as for so late in the season were set in the West during this period. Many of the record temperatures for both extremes are given in table 1.

4. FLOODS

Most of the areas of heavy precipitation east of the Rockies this month experienced moderate to severe flooding. The severity of the flooding in some areas, such as the Mississippi and Missouri River Basins in the Midwest and the Connecticut River Basin in New England, was compounded by rapid thawing of heavy to record-breaking late season snows.

In the Midwest early in the month record-breaking floods developed along the main stem of the Mississippi River from Burlington, Iowa to Quincy, Ill., and the highest stages since 1947 were reported from Hannibal to Winfield, Mo. During early April serious flooding also occurred in portions of the Missouri Basin. The greatest flooding since the turn of the century was reported at Akron, Iowa. The Missouri River flood extended from Nebraska City, Nebr., to the mouth with a 5–6-ft. overflow from Nebraska City to Atchison, Kans., exceeded at Rulo, Nebr., only by the record flooding in April 1952. Ice jams caused considerable flooding along the Elkhorn River in northeastern Nebraska.

Near the middle of the month heavy rains from Oklahoma to Illinois (up to 8 in. locally in Missouri) resulted in new overflows along streams that had only recently returned to their banks from the early April overflows. The Mississippi again left its banks from Hannibal to Louisiana, Mo., and the entire Illinois River was also in flood again near mid-month. In addition, rapid snowmelt

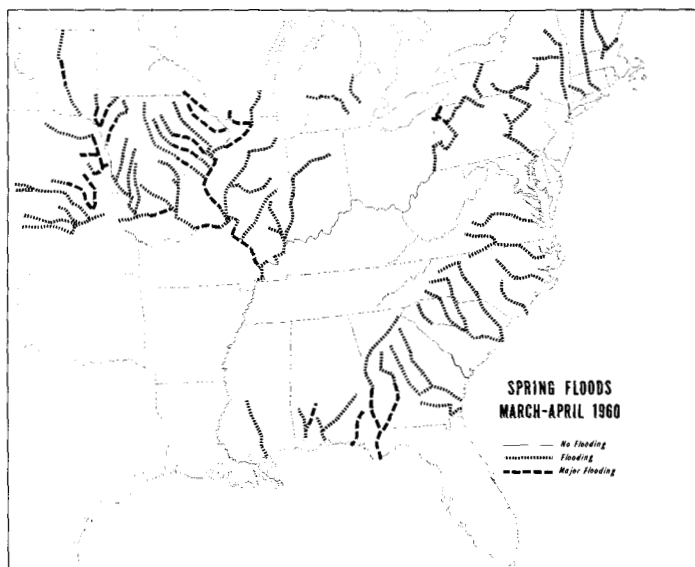


FIGURE 6.—Areas affected by flooding during late March and early April 1960. (Preliminary data from [3].)

produced some light overflows in the Red River of the North Basin in Minnesota, and flooding also developed again in places in the Kansas River Basin in Kansas. Later in the month, heavy rains resulted in considerable flooding in the northern counties of Wisconsin and the western counties of Upper Michigan.

In the Northeast, the most serious flooding since 1938, except for the flooding by rains from hurricane Diane in 1955, occurred along the Connecticut River in New England. The highest stages in several years were reported in the Merrimack River Basin in New Hampshire and Massachusetts. Minor to moderate flooding also occurred in the Hudson-Mohawk Basin in New York and along the entire Susquehanna River in New York and Pennsylvania.

In the Southeastern States the most significant flooding occurred in the Gulf drainage streams from the excessive rains early in the month. The most serious overflows occurred in parts of Georgia, Alabama, northwestern Florida, and Mississippi.

Areas affected by flooding during late March and early April are shown in figure 6. This résumé and figure 6 are based on the preliminary data reported in [3].

5. RESUMPTION OF BLOCKING AND THE NEW INDEX CYCLE

Above normal westerlies prevailed in the western part of the Northern Hemisphere for almost exactly one month, from the latter part of March to the latter part of April. This was the first significant period of high index since late December 1959, when the protracted index cycle of the recent winter began (lower part of fig. 7). Such a major index cycle is a frequent concomitant of the winter season [4], the most recent previous case being that of

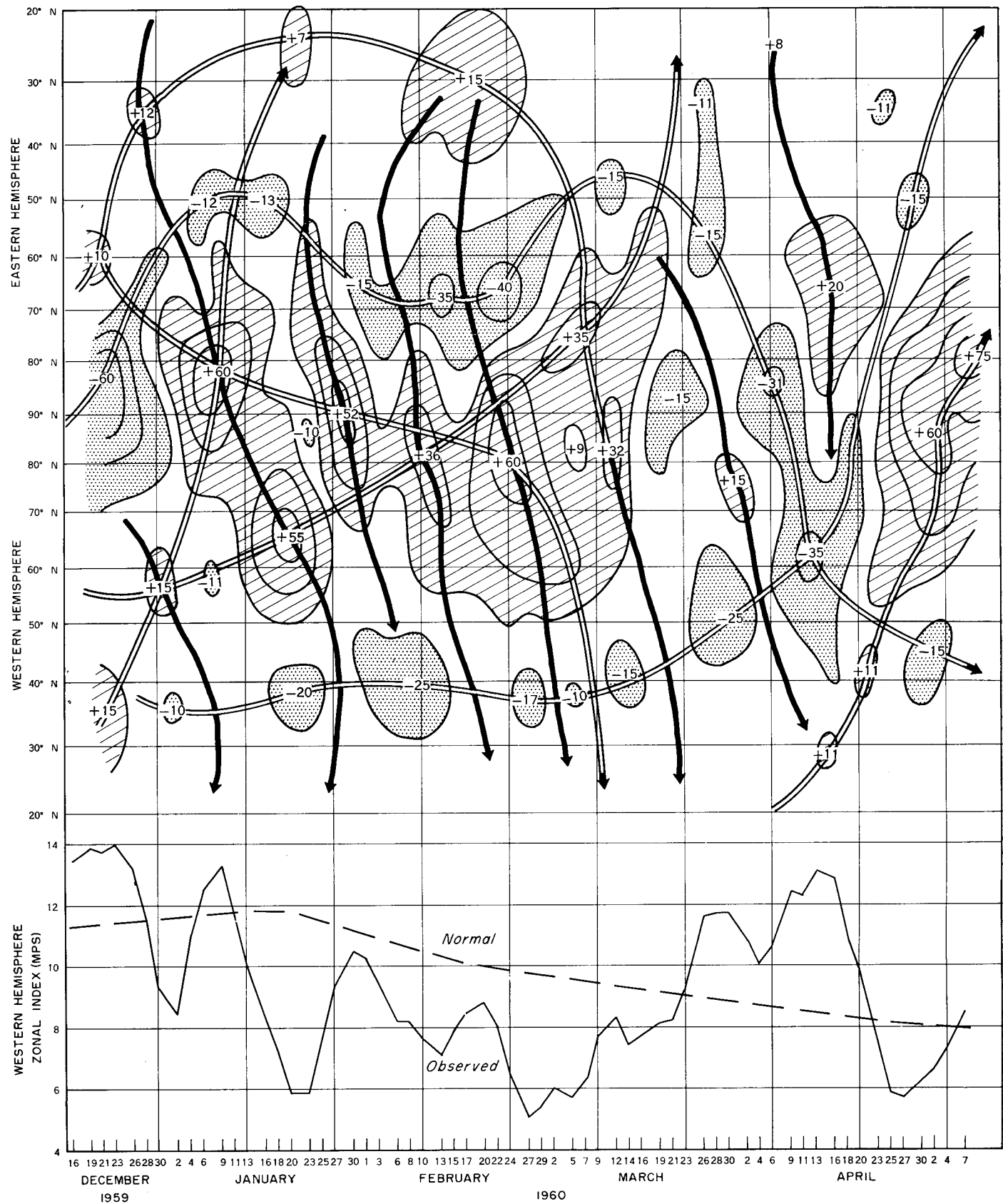


FIGURE 7.—Upper chart.—Time variation of latitudinally averaged 5-day mean 700-mb. height departures from normal (in tens of feet). Western and eastern halves of the Northern Hemisphere were averaged separately. Main feature was the predominance of positive height departures at high latitudes from late December to March and again in late April. See text for explanation of continuity of height anomaly cells. Lower Chart.—Time variation of 5-day mean 700-mb. zonal index in meters per second for the western section of the Northern Hemisphere between 35° and 55° N. The westerlies were above normal (dashed curve) from late March to April when negative anomalies dominated the high latitudes, and sank below normal when blocking resumed in late April.

the winter of 1958 [5]. These cycles are generally accompanied by persistent or recurrent "blocking" which in its broadest sense refers to the slowing down of the westerlies. This is brought about by relaxation of meridional pressure gradients due to above normal pressures (or positive height departures) at high latitudes and negative departures at low latitudes.

In order to shed some light on the resumption of blocking and the sudden depression of the westerlies in the latter part of April, the upper portion of figure 7 was prepared. This portrays the time variation of latitudinally-averaged 5-day mean departure from normal of 700-mb. height. Western (0° – 180° W.) and eastern (0° – 180° E.) departures were separately averaged for each 10° latitude circle. The horizontal scale encompasses a period of about $4\frac{1}{2}$ months extending from late December 1959 to early May 1960. The vertical scale represents increasing latitude in the western section of the Northern Hemisphere to the North Pole (90°), thence decreasing latitude in the eastern section, beginning and ending at latitude 20° N. This arrangement was planned in the hope of facilitating the detection of inter-sectional or transpolar exchanges of height anomalies, as well as the behavior of these anomalies relative to a broad space-time frame of reference. Since little is known about the physical aspects of continuity on a long time scale, the sequences of anomaly cells indicated in figure 7 are not necessarily unique. However, the individual 5-day mean anomaly patterns (prepared three times a week) were also considered.

In the upper part of figure 7, apparently very-long-period oscillations of height anomaly centers have been connected by double-lined arrows. In addition there appear to exist frequent short-period surges more or less orthogonal to the long-period oscillations. These have been indicated only for positive (or diminution of the negative) anomaly activity by heavy single lines and will be referred to as "transversals." The majority of these transversals appear to slant down the chart to the right, suggesting that the surges they represent originated primarily in the eastern part of the Northern Hemisphere and terminated in the subtropics of the western part. An additional set of negative transversals could have been drawn between the positive transversals but were omitted for clarity. It may be that these shorter-period surges are related to the circumpolar pressure waves discussed by Namias [6].

The remaining discussion is concerned primarily with the very-long-period oscillations shown by the double arrows in figure 7. The most obvious feature is the prolonged predominance of above normal heights at high latitudes from the end of December to the middle of March, when the westerlies remained well below normal in speed and latitude except for a brief period in early January. From mid-March to mid-April negative height anomalies were in the ascendancy at high latitudes, at which time the westerlies were stronger than, and north of, normal. Clearly evident in figure 7 is the dramatic

resumption of above normal heights in the polar regions near mid-April, associated with another sharp drop in the westerlies similar to that of late December 1959, and signaling the onset of a new index cycle.

It may be of value in this connection to study the long-period continuity of anomaly cells of like sign and their relationship to those of opposite sign. Perhaps the most obvious sequences are those of the negative cells which dominated lower latitudes almost continually during winter months. The cellular configuration may be interpreted to be a result of periodic intensification and diminution by the short-period anomaly surges of alternating sign (the transversals). The negative cells in the west increased in intensity with a northward trend from early January to mid-February but further northward movement, which might have ended the index cycle, appeared to have been thwarted by the existence of a long-period trans-sectional wave of height rises which, late in February, depressed the westerlies again to the lowest value of the year. Later in February the negative cells again began an ascending trend, and during late March and April they met with increasing support at higher latitudes from transpolar waves of negative anomaly from the east. This culminated in early April in an interaction at higher latitudes of the two long-period surges of negative anomaly from the opposite sides of the hemisphere. At this time the westerlies in the western part achieved their northernmost position and maximum speed since late December 1959. After the paths of the long-period negative cells diverged, blocking returned in strength to the higher latitudes in late April.

The sequences of the positive cells in figure 7, which constituted the blocking regime at higher latitudes, were not so easily discerned as those of the negative centers, due to their more complicated nature. It appears, however, that just as there were at least two distinct loci of negative cells, one in each part of the hemisphere, which were clearly defined because of their large separation, there probably also were two loci of positive centers. However, at higher latitudes these loci were difficult to distinguish because of their proximity. Therefore the connections of the positive cells which have been drawn at higher latitudes in figure 7 should be regarded as tentative, suggesting only one of the possible interpretations. This solution suggests a continuity of two simultaneous blocking surges at higher latitudes, the cellular character being the result of interference by the orthogonal short-period transpolar anomaly surges of alternating sign depicted by the single-line transversals.

The continuity of the averaged height anomalies in figure 7 suggests the possibility of some general lag relationships. For example the index cycle which started in late December 1959 and the one in late April were preceded by positive height departures of about 100 ft. or more in the subtropics. This condition seemed to apply equally well to both parts of the hemisphere prior to the onset of both major index cycles. In addition, it may be observed

from figure 7 that around mid-February in the eastern part of the hemisphere the subtropical height departures achieved a value of 150 ft. and, perhaps as a consequence, in March, the westerlies receded southward in that area. It thus appears that the eastern section had a double cycle during the winter, while the western part had only one prolonged major cycle, apparently due to the fact that subtropical positive anomalies averaged over the western part never achieved a sufficiently large value, such as observed in mid-December and mid-April. It should be noted that these suggestions are not inconsistent with the interpretation of "blocking action" in terms of large-scale energy considerations by Rex [7], who pointed out that narrow, high-velocity westerly streams often break down in a lower-energy mode of flow associated with amplification and low index.

From the foregoing discussion, one might speculate that index cycles commence after the sectional subtropical height anomalies have surpassed a certain positive value, perhaps near 100 ft. Although this value seems small compared with the values observed at middle and high latitudes, it must be realized that the degree to which an accumulation or deficiency of air is reflected by the anomaly value is markedly affected by latitude. Because of the convergence of the meridians, relatively small departures from normal at low latitudes possess greater potential if in some manner the increased mass is propagated to higher latitudes.

The index graphs for the 700-mb. subtropical and Polar westerlies (not shown) in the western section of the hemisphere verified the fact that the diminution of the westerlies preceding both the December and April declines at middle latitudes appeared first in the subtropics and last at the polar latitudes. This bears out the suggestion implied in figure 7 that the averaged value of the subtropical positive

anomaly may be important and perhaps critical in the subsequent evolution of the index cycle.

It should be pointed out, however, that the inferences discussed above may not apply to other cases. They do suggest an area for future study. In fact even the method of presentation shown in figure 7 should be subject to further study since the particular 180° longitude sectors used for averaging were chosen primarily because they were most conveniently obtainable in this form from the punched card data. Actually a much better division of the Northern Hemisphere, from the standpoint of blocking, would be one which does not split a well-known homogeneous blocking regime such as exists near the 0° meridian.

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